

**INDIVIDUAL DIFFERENCES IN SIGNED WORD LEARNING  
AMONG HEARING ADULTS**

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The Academic Faculty

by

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**INDIVIDUAL DIFFERENCES IN SIGNED WORD LEARNING  
AMONG HEARING INDIVIDUALS**

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## **SUMMARY**

The present study was conducted in order to identify predictors of signed word learning in hearing non-signers. 107 hearing non-signing adults participated, completing a sign-word paired associate learning task, two visuospatial, and three movement-based short-term memory (STM) tasks. Bivariate and semipartial correlations were derived and regression analyses conducted with the paired-associate task as the outcome variable. Results suggest movement-based and visuospatial STM are significantly and independently related to signed word learning. Additionally, a sign-based phonetic discrimination task accounted for variance in sign learning over and above movement-based STM, suggesting that phonetic discrimination is related to word learning. The results of this study have implications for theories of STM, language aptitude, and second language pedagogy.



# **CHAPTER 1**

## **INTRODUCTION**

The majority of individuals have little trouble mastering their first language and can, with diligence, learn multiple foreign languages. Yet, there is great variation in the amount of time and effort an individual must expend, with some mastering foreign languages easily and others only with great effort (Carroll, 1973; Dornyei & Skehan, 2003). Put another way, some individuals have greater language aptitude than others.

The great range in language aptitude and the resource demanding nature of learning a new language (Kemp, 1998) has stimulated the development and validation of assessments intended to predict foreign language learning success. Using course grades and other proficiency measures as outcome variables, language aptitude tests achieve validity coefficients around 0.5 (Ehrman & Oxford, 1995; Li, 2015), spurring their use by universities and government agencies who use them to select and place personnel into costly intensive language courses (Silva & White, 1993).

Curiously, however, the study of language learning aptitude has largely excluded signed languages, focusing almost entirely on spoken languages. As a result, it is unclear whether the claim that language aptitude, as measured by extant measures, is “equally relevant to any foreign language that [an] individual might choose to study (Carroll, 1973, p. 2),” encompasses the second language learning of signed languages.

One difference that may have a large impact on the validity of extant language aptitude measures is modality: signed languages are visuospatial-gestural languages

while spoken languages are aural-oral. Such a difference is likely to mediate the relationship between language aptitude and achievement.

The present study begins to address this dearth of research by identifying predictors of one aspect of language acquisition: word learning. While word learning is only one aspect of language acquisition, it is related to second language class performance (Cooper, 1964; Krug, Shafer, Dardick, Magalis, & Parenté, 2002), grammar acquisition (for a review, see Bates & Goldman, 1997), and language aptitude (Cooper, 1964; Li, 2015). Moreover, as will be detailed below, word learning appears to be especially reliant on modality-specific processes. For these reasons, word learning is an excellent starting point to begin addressing theoretical and practical concerns related to learning a second language in a second modality.

## **CHAPTER 2**

### **BACKGROUND**

#### **2.1 Language Aptitude**

Research in language aptitude is largely concerned with identifying the processes involved in second language (L2) learning and predicting L2 learning success. There is evidence, however, to indicate that language aptitude applies to native language learning as well. Whether or not the same construct of language aptitude applies to signed languages is an unanswered question.

Carroll (1958) explored the nature of language aptitude by conducting a factor analytic study using two language aptitude batteries. Using an oblique rotation, Carroll was able to identify seven factors: verbal knowledge, linguistic interest, associative memory, sound-symbol association, inductive language learning ability, grammatical sensitivity, and speed of association. Several other researchers have conducted their own factor analytic studies and, to a great extent, corroborated Carroll's findings (Pimsleur, Stockwell, & Comrey, 1962; Sparks, Humbach, Patton, & Ganschow, 2011).

Carroll (1964) offered a more theoretically grounded and parsimonious account of language aptitude, citing four highly related but distinguishable factors: phonetic coding ability (the ability to encode perceptual-linguistic material so that it can be remembered), grammatical sensitivity ("the ability to 'handle' grammar (p. 129)"), rote memory (ones ability to remember associations), and inductive language learning (the ability to infer the structure of language from linguistic samples). Linguistic interest (i.e., motivation) is

considered a separate construct while the other excluded factors were viewed as poor predictors and therefore unrelated to language aptitude.

To validate the construct of language aptitude, Li (2015) conducted a meta-analysis employing Carroll's components with one difference: inductive language learning and grammatical sensitivity were grouped together as "language analytic ability." On the whole, language aptitude tests were predictive of L2 achievement with a correlation of 0.49. The subcomponents of phonetic coding, language analytic ability, and rote memory had coefficients of 0.45, 0.38, and 0.24, respectively. Li also assessed the relationship between these components and various markers of L2 achievement. Germane to the present study is that phonetic coding was the strongest predictor of L2 vocabulary with a coefficient of 0.38.

Sparks, Ganschow, & Pohlman (1989) posit that language aptitude relates to native language (L1) achievement as well. They proposed their Linguistic Coding Deficit Hypothesis (LCDH) to account for some individuals' difficulties in mastering L2s. They postulate that L2 difficulties stem from the same processes required for mastering the L1, notably phonological/orthographic and syntactic processes (Sparks et al., 1998).

Many studies support the LCDH. Sparks et al. (2006) for example, measured students' L1 language abilities, intelligence, and foreign language ability and found that L1 language abilities were the best predictors of L2 achievement. In a factor analytic study, Sparks et al. (2011) analyzed the relationships between a variety of L1 skills, L2 aptitude, achievement, and affective measures. They identified four factors—labeled linguistic analysis, phonology/orthography, IQ/memory, and self-perceptions—corroborating and extending earlier studies of language aptitude (e.g., Pimsleur,

Stockwell, & Comfrey, 1962; Carroll, 1967). Two observations must be made: first, L1 and L2 components were combined within the first two factors, supporting a unitary construct; second, phonology/orthography accounted for the second greatest amount of variance.

While the study by Sparks et al. (2011) concluded that L1 and L2 language acquisition are related and, therefore, are manifestations of general linguistic ability, it remains to be seen whether L2 *sign language* acquisition is subsumed by this same factor. I am aware of only one (unpublished) study specifically investigating language aptitude for signed languages. C. Stone examined the predictive validity of the Modern Language Aptitude Test for sign language acquisition and found that it was predictive of first semester sign language course grades (C. Stone, personal communication, February 20, 2015). Caution, however, should be taken in interpreting these results, as the sample size was relatively small, with only 22 students. Furthermore, as mentioned above and will be detailed further, phonetic coding is a significant predictor of language acquisition and appears to be mediated by modality.

## **2.2 Phonological Short-Term Memory**

One may reasonably conclude that because signed and spoken languages differ in modality, the processes involved in encoding perceptual-linguistic material (i.e., phonetic coding) could differ as well. There is the possibility, however, that in typically developing individuals, the bulk or perhaps entirety of individual differences in phonetic coding ability is due to the linguistic rather than perceptual aspect of the construct. In fact, research on phonological short-term memory (to be reviewed below) indicates that phonetic coding is substantially reliant on perceptual processes.

### **2.2.1 Phonological Short-Term Memory and the Phonological Loop**

Phonological short-term memory (PSTM) can be defined as short-term memory for linguistic or language-like material, such as words and nonwords. In the multicomponent model of working memory, PSTM is served by the phonological loop, a system composed of a temporary phonologic store and an articulatory rehearsal mechanism that aids in maintaining that information (for a review, see Baddeley, 2012). The distinction between phonetic coding and PSTM is largely due to the articulatory component of the phonological loop: tasks that inhibit or minimize the involvement of the articulatory loop are considered “purer” measures of coding ability (Gathercole, 2006).

A number of studies have found that measures of spoken-PSTM, such as digit span and nonword repetition, serve as predictors of L1 and L2 word learning (WL) in children (Gathercole & Baddeley, 1989; Gathercole, Hitch, Service, & Martin, 1997; Gathercole, Willis, Baddeley, & Emslie, 1994; Masoura & Gathercole, 1999, 2005; Masoura, Gathercole, & Bablekou, 2004) and adults (Atkins & Baddeley, 1998; Gupta, 2003; Martin & Ellis, 2012; O'Brien, Segalowitz, Collentine, & Freed, 2006; O'Brien, Segalowitz, Freed, & Collentine, 2007). Moreover, PSTM correlates with grammar acquisition in hearing individuals (Martin & Ellis, 2012; Verhagen & Leseman, 2016) and sign language ability in interpreters (Gómez, Molina, Benítez, & de Torres, 2007) and Deaf children (Mann, Marshall, Mason, & Morgan, 2010).

Gathercole (2006) hypothesizes that the relationship between PSTM and WL exists because both rely on similar coding and output processes. She cautions, however, that this relationship is strongest when words in the memory task consist of unfamiliar

phonological structures such as nonwords or words from an unknown L2— the more unfamiliar the phonologic material, the less long-term lexical knowledge (i.e., long-term memory, LTM) can mediate the relationship between PSTM and WL (Gathercole, 1995). As a consequence, nonword repetition is generally viewed as a better predictor of WL than digit span (Baddeley, Gathercole, & Papagno, 1998; Gathercole et al., 1994) and the relationship between nonword repetition of L2 words and L2 WL attenuates as individuals become more proficient in the L2 (Masoura & Gathercole, 2005).

#### *2.2.1.1 PSTM and Perceptual Processes in Spoken Languages*

There is an abundance of literature on the phonological loop in spoken languages that indicates that hearing individuals rely on auditory and speech-motor (i.e., articulatory) processes while encoding verbal information (e.g., Baddeley, 2003; Baddeley, 2012; Baddeley et al., 1998); here I review only the most pertinent evidence.

In hearing individuals, spoken-PSTM is disrupted by similarity (Baddeley, 1966; Conrad & Hull, 1964), item length (Baddeley, Thomson, & Buchanan, 1975), articulatory suppression (Baddeley, 1986), and irrelevant speech (Colle & Welsh, 1976) and sounds (such as tones and instrumental music; Jones & Macken, 1993; Salamé & Baddeley, 1989).

Briefly, the similarity effect occurs when to-be-remembered stimuli sound similar—sets of phonologically similar items (e.g., *B, E, G, P, T*) are not remembered as well as phonologically dissimilar items (e.g., *D, X, I, L, Q*)—suggesting that linguistic material is encoded in a sound-based code. The length effect denotes the observation that performance in a PSTM task is reduced when sets consist of relatively longer items. This suggests that items are being rehearsed (overtly or covertly) in their surface form: longer

items take more time to rehearse and therefore cannot be refreshed before they decay from the temporary store. Articulatory suppression—when one is asked to repeat a short word or syllable during encoding—occupies the rehearsal mechanism, leaving only the temporary store, resulting in a reduction in performance compared to a non-suppressed condition.

Interestingly, when phonological stimuli are presented visually (as written words or pictures), both the similarity and length effect are nullified by articulatory suppression (Baddeley, Lewis, & Vallar, 1984); under articulatory suppression and aural presentation, however, the similarity effect occurs while the length effect does not. Baddeley, Lewis, and Vallar (1984) view this pattern of results as further proof of the phonological loop: visually presented verbal items must be phonologically recoded to gain access to the phonological store, however, this recoding is blocked by articulatory suppression. On the other hand, when verbal stimuli are presented aurally, sound similarity can be perceived even during articulatory suppression. In either case, the articulatory loop is engaged by articulatory suppression and therefore the word length effect is not manifested.

Finally, irrelevant speech (Colle & Welsh, 1976) and non-speech sounds (such as tones and instrumental music; Jones & Macken, 1993; Salamé & Baddeley, 1989) also impair spoken-PSTM. Neath (2000) hypothesizes that some features of the irrelevant sounds are encoded during a STM task and serve as cues during recall. These cues are invalid and therefore disrupt performance.

To summarize, hearing individuals perceive and encode surface level features of verbal material in PSTM and utilize speech-motor (or articulatory) processes (overtly or covertly) to aid in retaining said material. This is not to say that these are the only



mnemonic codes utilized when retaining phonologic material in STM, simply that perceptual and motor coding are also used and seem to be important for recalling verbal events (cf., Buchsbaum & D'Esposito, 2008; Jones, Macken, & Nicholls, 2004; Wilson, 2001)

#### *2.2.1.2 PSTM and Perceptual Processes in Signed Languages*

Evidence for a phonological loop in sign language is strikingly similar to that of spoken language, however, as a visuospatial-gestural language, there are differences. Before reviewing these studies, I will provide a brief overview of sign phonology.

The majority of signs in signed languages around the world are monosyllabic (Brentari, 1999); rather than a sequential ordering of phonemes, signs are composed of the simultaneous presentation of various phonological parameters. The three parameters that all signs consist of are handshape, movement, and location (Klima & Bellugi, 1979).

Just as spoken languages make use of only a small portion of all the possible vocal sounds humans can make, signed languages make use of only a small number of all the movements the hands can make. American Sign Language (ASL), for example, consists of 55 phonemes (for reference, English uses 44; Marschark, 1997).

Figure 1 depicts a nonsign making use of the phonological parameters of ASL. The sign begins with the right, dominant hand holding a “V” handshape, while the non-dominant hand acts as a base, maintaining a flat or “B” handshape, palm up. The location is in neutral space, right in front of the torso. The sign ends after a straight movement of the dominant hand out to the side of the body. Note, this nonsign is similar to the ASL sign for “two weeks,” but differs in the orientation of the base hand and in the length of the movement.



Figure 1. Example of a nonsign.

In a series of studies, Wilson and Emmorey provided evidence for a phonological loop in sign language, showing that just as in spoken languages, signed-PSTM is disrupted by similarity, word length, articulatory suppression, and irrelevant stimuli (Wilson & Emmorey, 1997, 1998, 2003). Of course, because signed languages make use of a visuospatial-gestural rather than aural-oral phonology, Wilson and Emmorey used sign-based manipulations. For example, the similarity effect was elicited by presenting similar *looking* (as opposed to *sounding*) stimuli to Deaf individuals (Wilson & Emmorey, 1997). Similarly, asking Deaf participants to produce a nonsign during encoding blocked the articulatory rehearsal mechanism (which signers would involve the hands and gestures rather than the mouth and speech), evoking the suppression effect (Wilson & Emmorey, 1997); the length effect was evoked by composing sets of signs with longer motions that take a correspondingly longer time to produce (Wilson & Emmorey, 1998); and the irrelevant stimuli effect was evoked by displaying irrelevant nonsigns or unnamable rotating figures during a retention interval (Wilson & Emmorey, 2003).

### *2.2.1.3 Phonetic Coding: Evidence from Neuroimaging*

Neuroimaging studies support the assertion that hearing-speakers and Deaf-signers use different sets of encoding processes during short-term memory tasks (Campbell, MacSweeney, & Waters, 2008; Rönnerberg, Rudner, & Ingvar, 2004; Rudner, 2015; Rudner, Andin, & Rönnerberg, 2009; Williams, Darcy, & Newman, 2016b). Rönnerberg et al. (2004), for example, conducted a PET study comparing STM for signed and spoken stimuli. They found increased activation in bilateral temporal, bilateral parietal, and left premotor activation when signed sentences were presented to Deaf individuals compared to when hearing subjects heard or saw translations of the sentences. Bavelier et al. (2008), conducting an fMRI study, also found differences: Deaf signers exhibited greater activation of visual processing areas while hearing speakers showed greater activation of areas associated with auditory processing.

While differences are clearly manifest, it is important to note the similarities between signed and spoken languages. Take the two imaging studies reported above: Rönnerberg, Rudner, and Ingvar (2004) found similar levels of activation in Broca's area while Bavelier et al. (2008) noted similarities in frontal parietal areas associated with STM (Wager & Smith, 2003). Moreover, in an fMRI study, Williams, Darcy, and Newman (2015) found similar levels of activation in areas associated with phonetic segmentation in hearing adults tasked with categorizing English, Spanish, and ASL lexical items according to phonetic categories.

Taken together, the behavioral and neuroimaging studies above indicate that both signers and speakers make use of phonetic, or perceptual-linguistic, coding. The evidence suggests that individuals confronted with either sign- or spoken-PSTM tasks engage

similar linguistic processes but differ in their recruitment of perceptual processes: signed languages make use of visuospatial and manual-motor processes while spoken languages make use of sound and speech-motor processing.

### **2.2.2 PSTM and Language Acquisition**

While LTM and other factors may mediate the relationship between PSTM and WL (LTM, see section 2.2.1, above; other factors, see Martin & Ellis, 2012; Verhagen & Leseman, 2016), a direct link does appear to exist. Baddeley, Papagno, and Vallar (1988), found that a patient with impaired spoken-PSTM performed in the normal range on a paired-associate WL task when both words in the pairs were composed of familiar L1 words but performed significantly below average when one of the words was from an unfamiliar L2. Baddeley and colleagues posited that when pairs consisted of L1 words, the patient was able to draw on lexical knowledge and associative-semantic abilities but not when one of the words was unfamiliar— in that case, the burden was primarily on the phonological store component of the phonological loop, or in other words, on phonetic coding. Experimental studies of WL in unimpaired participants substantiate this conclusion. In order to artificially disrupt spoken-PSTM, Papagno, Valentine, and Baddeley (1991) utilized articulatory suppression while Papagno and Vallar (1992) manipulated phonological similarity and word length. Overall, they found that performance suffered when one of the words in the pairs was from an unfamiliar language or a nonword but not when pairs were entirely constructed of L1 words.

### **2.3 Present Study**

To summarize, research indicates that language learning is reliant on phonetic coding which is itself reliant, to a great extent, on perceptual abilities. In spoken

languages, PSTM is disrupted by sound and speech-motor manipulations, while in signed languages, visuospatial and manual-motor manipulations disrupt PSTM. An abundance of research in spoken-WL also indicates that PSTM is related to WL and we observe that the same perceptual and motor manipulations that disrupt spoken-PSTM also disrupt spoken-WL. Unfortunately, there are few individual differences studies investigating sign language acquisition, however, we can hypothesize that perceptual abilities should be related to signed-WL.

Accordingly, the present study aimed to identify predictors of signed-WL in hearing non-signers. This population was chosen precisely because they have little to no experience with signed languages, and as such, the confounding role LTM should be minimized. Consequently, the estimates derived by this study should be closer to the true values.

Given the research reviewed above, signed-WL should be related to signed-PSTM. However, given that this population is composed of non-signers, I hypothesized that the relationship between signed-PSTM and signed-WL is due to the perceptual rather than linguistic nature of the stimuli. In order to assess this hypothesis, the present study uses two types of movement-based STM tasks: signed-PSTM and nonverbal-movement STM.

The research reviewed above indicated that signed-PSTM is disrupted by visuospatial manipulations, and in fact, Shaw (2011) identified visuospatial ability as a predictor of sign interpreting ability; therefore, I predicted that visuospatial ability is also related to signed-WL. Furthermore, because there is evidence that visuospatial STM can be divided into visual and spatial STM (Darling, Della Sala, & Logie, 2007; Darling,

Della Sala, Logie, & Cantagallo, 2006; Della Sala, Gray, Baddeley, Allamano, & Wilson, 1999), I chose to use tasks that, in theory, load more heavily on one or the other component of visuospatial STM.

Finally, while data collection was underway for this study, Williams, Darcy, and Newman (2016a) reported the results of their study with a small sample of novice American Sign Language learners. They found that English phonetic categorization was related to sign vocabulary growth, suggesting that phonetic categorization is a general linguistic ability. In regards to the present study, one of the signed-PSTM tasks happens to require phonetic discrimination, and, in light of Williams and colleagues' finding, I hypothesized that phonetic discrimination is related to signed-WL.

## **CHAPTER 3**

### **METHODS**

#### **3.1 PARTICIPANTS**

107 participants between the ages of 18 and 35 ( $\bar{X} = 21.7$ ,  $SD = 4.1$ , 55% female) were recruited from the university subject pool (55%) and surrounding area (45%), including local colleges and universities. Participants recruited from the university subject pool were compensated with course credit; all others received \$25. All participants were right handed, fluent in English, with normal or corrected-to-normal vision, and free of any upper-body movement disorder.

#### **3.2 Procedure**

All tasks were administered in a single, private session lasting no more than two hours, including an optional break. Tasks were programmed with PsychoPy (Peirce, 2007) and presented on a MacBook Pro laptop. Two tasks required reproducing movements and were filmed using a handheld camera on a tripod so they could be scored later.

Participants completed three movement-based (two measures of signed-PSTM and one nonverbal-movement STM task) and two visuospatial STM tasks (one static-visual and the other dynamic-spatial); a sign-word paired associate learning task; a questionnaire asking for demographic and achievement test scores; and, for those participants recruited from the university subject pool, a record release form to access achievement test records. Unfortunately, few participants self-reported achievement scores and those that we were able to access were generally in the top tenth percentile

resulting in a highly restricted range of scores; as a result, achievement score data will not be reported here.

Written consent to participate in the study was always obtained at the beginning of the session; the questionnaire and, when applicable, the record release form at the end; the remaining tasks were administered using a Latin-square design. One to three practice items with feedback were provided for all tasks.

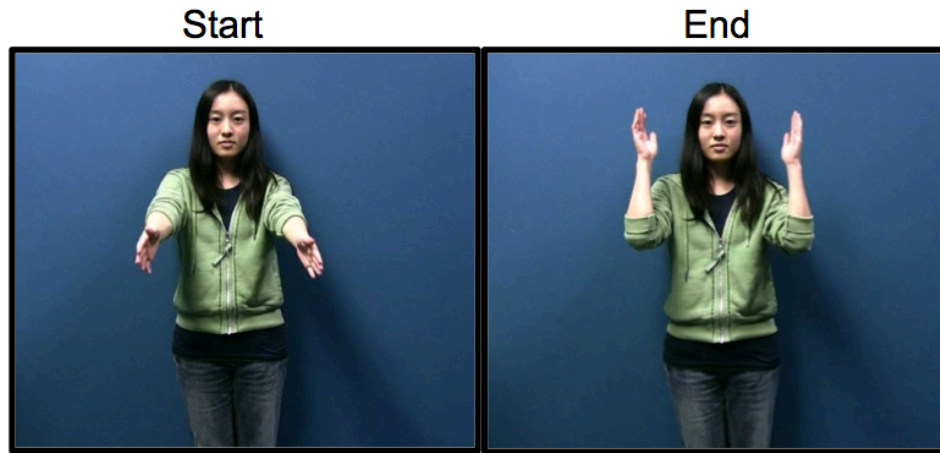
### **3.2.1 Tasks**

#### *3.2.1.1 Movement-based STM*

**Movement Span (MoveSpan; Figure 2).** The MoveSpan task (Wu & Coulson, 2014) is a measure of nonverbal-movement STM. Movements in this task consist of gestures that are difficult to verbally recode and do not necessarily follow the phonotactics of any particular sign language (e.g., there is no dominant hand, a number of movements are asymmetric, “disyllabic”, and/or place one of the hands fully behind the back; see Orfanidou, Adam, McQueen, & Morgan, 2009).

Individuals are presented with three sets each of one to five movements. After viewing a set, participants freely recall movements at their own pace by mirroring them. Raters, trained to a .80 ICC (2,1; Shrout & Fleiss, 1979) consistency criterion, later scored participants’ recorded responses, awarding one point for every movement correctly recalled and a half-point for a movement that deviated from the target by one criterion (see Appendix A for scoring instructions). Movements within a set were fixed, however, sets were presented randomly. MoveSpan score was calculated as the total number of points earned across all sets, thus the maximum score was 45 points.



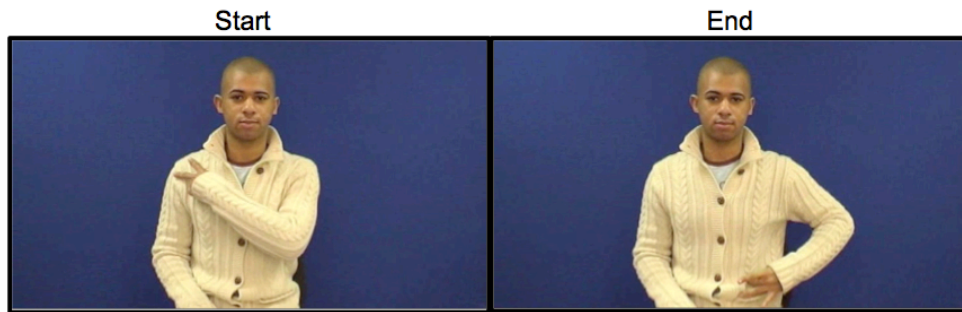


*Figure 2.* A single movement from the MoveSpan created by Wu and Coulson (2014). Sets consisted of one to five such movements.

**Nonsign Repetition Task (NSRT; Figure 3).** The NSRT (Mann et al., 2010) was designed to be a measure of signed-PSTM. It consists of 40 nonsigns that obey British Sign Language phonotactics but are themselves meaningless (Mann et al., 2010, p. 15). Participants view video clips of nonsigns, one at a time, and are expected to mirror the items immediately after presentation. The decision to ask participants to mirror the items deviates from the protocol followed by Mann et al. (2010) but was made to maintain consistency with the MoveSpan task and to curtail errors due to participants confounding instructions across tasks. Because all single-handed signs were performed with the left hand by the model, mirroring these signs required participants to use their right hand.

Items were presented randomly and participant performance was recorded and scored off-line by raters trained to a .80 ICC criterion. Unlike the MoveSpan—and consistent with Mann et al. (2010)—scoring was dichotomous, with one point awarded for correctly mirrored nonsigns and zero points for reproductions that differed from the target nonsign by one parameter (see Appendix B for scoring instructions). Participant

scores on the NSRT were calculated by summing the total points awarded, thus the maximum score was 40.



*Figure 3.* An example item from the Nonsign Repetition Task (Mann et al, 2010).

**Non-Sign Paired Task (NSPT; Figure 4).** The Nonsign Paired Task was designed in house as an automated signed-PSTM task, however, as will become clear below, this task may also be viewed as a phonetic discrimination task.

The NSPT is modeled after Bochner and colleagues' American Sign Language Discrimination Test (ASL-DT; Bochner, Christie, Hauser, & Searls, 2011; Bochner et al., 2015). Our tasks differ, however, in both function and form: the NSPT, designed as an aptitude measure, consists of 55 ASL nonsign pairs while the ASL-DT consists of 48 pairs of ASL sentences and is intended as an assessment of ASL proficiency.

In the NSPT, participants view a target nonsign and must judge whether a reproduction was the same or different from the target according to specified criteria. A parametric approach, with movement, orientation, and handshape as categories, was used to create all nonsigns (for greater detail, see Wilson & Fox, 2007) and were judged phonotactically permissible by a native signer of American Sign Language .

Reproductions were designed to either faithfully reproduce the target or differ by one parameter from the target.



*Figure 4.* An example from the Nonsign Paired Task (NSPT). After seeing the target and either item 1A in the first block or 1B in the second, the response screen appears: “Were the gestures you just saw the same or different? Click to make your choice.” Pictures show the final position of a nonsign.

Participants begin the NSPT by viewing a brief (2min, 44s) instructional video. The video introduces the participant to the task, instructs them on the judgment criteria, and provides examples. At the conclusion of the video, participants are provided with a “cheat sheet” reminding them of the judging criteria. Next the participant completes three practice items with a researcher providing feedback. After completing the practice and receiving feedback, the main portion of the task begins.

There are two blocks. In both blocks, participants view a target nonsign produced by a male performer. Immediately after this, the participant views a female performer assistant “attempt” to copy the target nonsign. The second block used the exact same

target nonsigns but a different female performer attempted the reproductions. Different researchers were used for the target and reproductions to focus the participants' attention on the phonological properties of sign language.

Importantly, for an individual to get an item correct, both judgments (across the two blocks) had to be correct. This reduces the chance of guessing from 50% to 25% and is theoretically justifiable as well. An example using English words may help. If the target was /bat/, two possible reproductions may be /bat/ and /vat/. To receive a point for this item, one would have to judge the first reproduction as *same* and the second as *different*. Doing so provides information about an individual's ability to encode and discriminate two phonemes. An easier item may have one compare /bat/ to /rat/. Note that in these examples, the first phoneme is changed, however, any phoneme can be changed or a phoneme may be deleted or added. Items in the NSPT were analogously designed to provide a range in item difficulty. A future study will detail the manipulations used (including sign complexity) and their effect on item difficulty.

### 3.2.1.2 Visuospatial STM Tasks

**Corsi Block Tapping Task (Corsi; Figure 5).** The Corsi task (Milner, 1971) is a visuospatial STM task that loads more heavily on spatial processing (Della Sala et al., 1999). Items consisted of 4-9 blocks flashing sequentially for 1 second each. After presentation of an item, participants were to immediately click the blocks in the same order they had flashed. There were three blocks, each set length was randomly presented once within a block of trials, therefore each set length was presented three times. Participants' scores were calculated using a partial scoring method in which a single point was awarded for each square correctly recalled in its serial position.

**Pattern Span (PatSpan; Figure 6).** This task was modeled after the Visual Pattern Test, which has been shown to load more heavily on visual processing (Della Sala et al., 1999). Participants viewed items consisting of figures produced from 4 to 13 blocks for 3000ms. After presentation, static was presented for 300ms; subsequently, participants were to click on the boxes displayed on the computer screen to reproduce the figure they had just viewed. There were three different figures for each set length; figures were the same for all participants though presentation was randomized. PatSpan scores were calculated by awarding a single point for every *figure* correctly recalled.

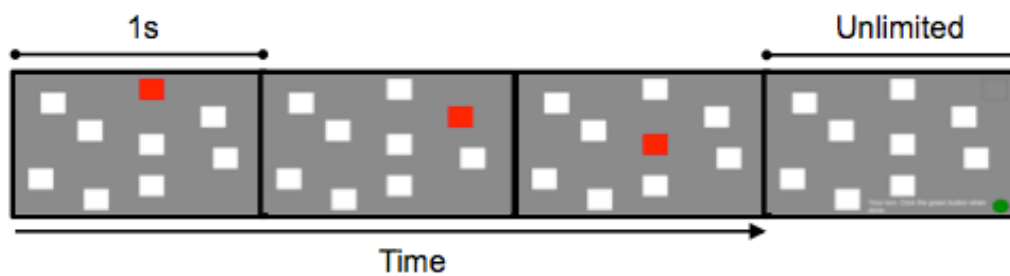


Figure 5. An example of a practice Corsi trial, set size three.

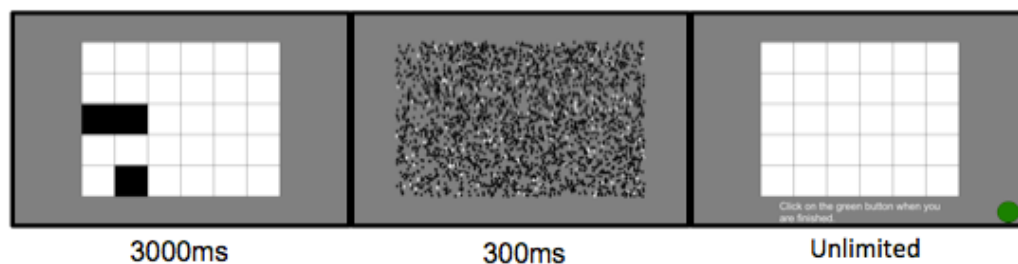


Figure 6. An example of a practice PatSpan trial, set size three. The final frame depicts the response screen, instructing participants to “click on the green button when you are finished.”

### *3.2.1.3 Sign Learning*

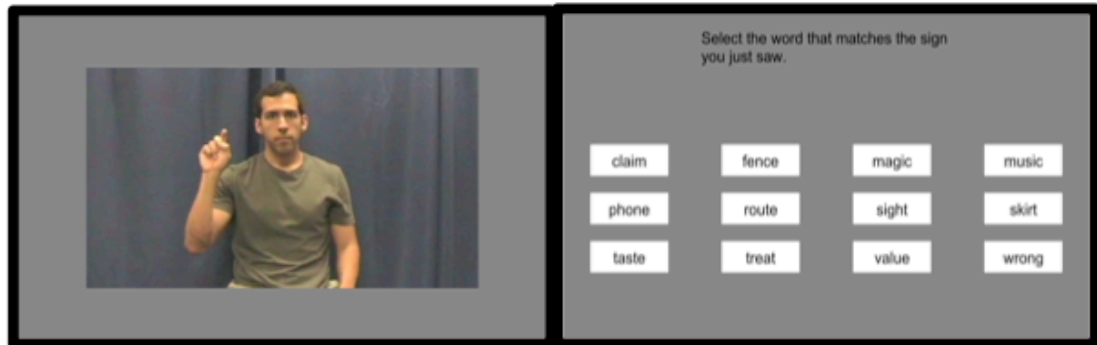
**Sign Learning Task (SLT; Figure 7).** The criterion variable, the Sign Learning Task (SLT), is a paired-associate learning task employing a study-test learning procedure. Such tasks have been shown to result in long-term retention (Seibert, 1930; Thorndike, 1908) and correlate with verbal ability and language aptitude (Cooper, 1964; Hundal & Horn, 1977; Kyllonen & Tirre, 1988; Kyllonen & Woltz, 1989). Moreover, utilizing paired-associate learning in the lab—as opposed to assessing vocabulary growth in hearing beginning signers—provides a greater degree of control, for example, in the amount of time and method of study.

Two sets of 12 nonsign-written English word pairs were presented. The nonsign, on average, took 3.5s to view and was immediately followed by its randomly associated English word pair, presented for 1s. Nonsigns were created using a combinatorial approach and deemed phonotactically permissible by a fluent ASL signer. All English words were five-letter, high-frequency nouns selected from the SUBTLEX-US corpus (Brysbaert & New, 2009). The dependent variable was the total number of pairs correctly recalled.

A



B

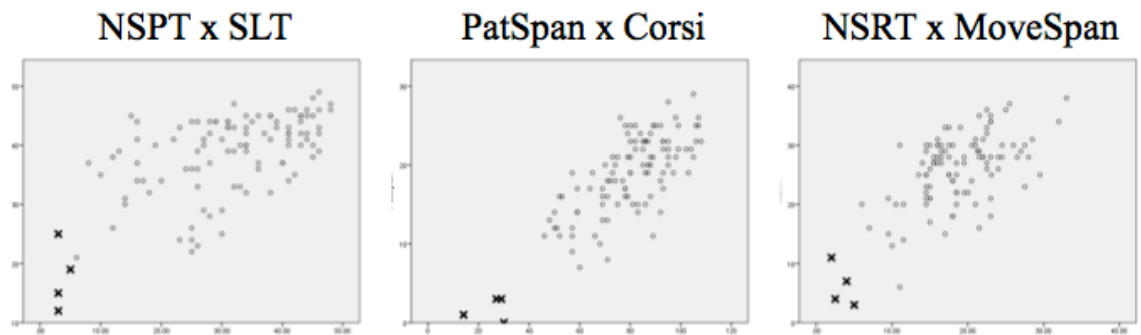


*Figure 7.* Depiction of the Sign Learning Task. Panel A shows a nonsign-word pair from the study block of a trial. Panel B shows an item from the test block: the cue is presented followed by the response screen showing all words from this set in alphabetical order.

## CHAPTER 4

### RESULTS

The data were assessed for univariate outliers using a cut-off z-score of 3.29 (Field, 2013) and by examination of a variety of graphical representations. Four participants achieved z-scores at or above the cut-off on at least one variable and evidence from a number of scatter plots indicated that these participants might be representative of a different population (see Figure 8; note bolded markers). As a result, these four individuals were removed from further analysis, leaving the final sample size at 103.



*Figure 8.* Representative scatter plots. Note: the same four cases are represented by bolded markers.

Descriptive statistics and reliabilities (Cronbach's alpha) are provided in Table 1. The items used to calculate Cronbach's alpha were derived as follows: For the SLT, the "items" consisted of subscores derived by summing the points awarded for correctly identifying each instance of a particular word; MoveSpan, Corsi, and PatSpan reliabilities were each calculated by forming three subscores composed of one instance of each set length (see Engle, Tuholski, Laughlin, & Conway, 1999); NSPT and NSRT reliabilities



were calculated using each item as a score (i.e., as is typical). All coefficient alphas were near or above 0.80, indicating acceptable reliabilities.

**Table 1.** Descriptive statistics for all tasks.

Task	Min <sup>1</sup>	Max <sup>1</sup>	Mean (SD) <sup>1</sup>	Skew	Kurtosis	$\alpha$
SLT	13	100	66 (22)	-0.47	-0.59	.90
MoveSpan	13	73	42 (12)	0.19	0.12	.80
NSRT	15	95	65 (14)	-0.63	0.70	.77
NSPT	38	89	71 (11)	-1.02	0.44	.80
Corsi	39	92	69 (13)	-0.32	-0.55	.80
PatSpan	23	97	63 (16)	-0.35	-0.52	.86

<sup>1</sup>Expressed as percent of score possible.

Note: SLT = Sign Learning Task, NSPT = Non-Sign Paired-Discrimination Task, MoveSpan = Movement Span, Corsi = Corsi Block Tapping Task, PatSpan = Pattern Span

Tables 2 and 3 display the results of the bivariate and partial correlational analyses, respectively. The bivariate correlational analysis was conducted to assess relationships amongst all variables. As can be seen in Table 2, all STM tasks, regardless of the linguistic nature of the stimuli, were positively related to the signed WL task, SLT, with correlations ranging between .40 and .54. The partial correlational analysis was conducted to control for visuospatial processing, which is necessarily engaged during movement processing (Vicary, Robbins, Calvo-Merino, & Stevens, 2014; Vicary & Stevens, 2014). After controlling for visuospatial STM, the movement-based STM tasks and the SLT remained positively correlated with each other, indicating a significant amount of shared variance (Table 3).

**Table 2.** Correlation matrix

	1	2	3	4	5
1 SLT					
2 MoveSpan	.504				
3 NSRT	.406	.524			
4 NSPT	.498	.506	.453		
5 Corsi	.400	.391	.282	.403	
6 PatSpan	.535	.569	.373	.550	.685

Note: all correlations significant,  $p < .01$ , one-tailed.

**Table 3.** Partial correlations controlling for visuospatial STM

	1	2	3
1 SLT			
2 MoveSpan	.288		
3 NSRT	.262	.409	
4 NSPT	.287	.282	.319

Note: all correlations significant,  $p < .01$ , one-tailed; Pattern Span and Corsi Tasks partialled out.

Next, regression analyses were conducted to investigate the individual contributions of signed-PSTM, nonverbal-movement, visual, and spatial STM in predicting sign learning. The first analysis was hierarchical and included one measure of each of the aforementioned constructs, with SLT as the outcome variable (Table 4). Entering the MoveSpan task in the first step resulted in a significant model,  $F(1,101) = 34.40$ ,  $p < .001$ ,  $R^2 = 25.4\%$ . The addition of the NSRT in the second step did not result in a significant increase in  $R^2$ ,  $F(1,100) = 3.87$ ,  $p = .052$ ,  $\Delta R^2 = 2.8\%$ . Entering the PatSpan task in the third step did significantly increase  $R^2$ ,  $F(1,99) = 12.72$ ,  $p = .001$ ,  $\Delta R^2 = 8.2\%$ , however, entering the Corsi task in the fourth step did not,  $F(1,98) = 0.24$ ,  $p = .63$ ,  $\Delta R^2 = 0.2\%$ . These results suggest that the predictors are chiefly representative of two constructs: movement and visuospatial STM.

**Table 4: Hierarchical regression analysis with SLT as the outcome variable**

		$\beta$	sr	Sig.	R	$R^2$	Sig F. Change
1	MoveSpan	.504	.504	.000	.504	.254	.000
2	MoveSpan	.401	.342	.000			
	NSRT	.196	.167	.052	.531	.282	.052
3	MoveSpan	.221	.166	.041			
	NSRT	.160	.135	.095	.603	.364	.001
	PatSpan	.350	.286	.001			
4	MoveSpan	.222	.167	.041			
	NSRT	.158	.133	.100	.604	.365	.628
	PatSpan	.313	.204	.013			
	Corsi	.054	.039	.628			

Note: All models significant at  $p < 0.05$ . SLT = Sign Learning Task; MoveSpan = Movement Span; NSRT = Nonsign Repetition Task; PatSpan = Pattern Span; Corsi = Corsi Task.

Finally, a regression analyses was conducted using the NSPT in place of the NSRT. The NSPT is a measure of signed-PSTM, however, it also requires phonetic discrimination. Given that the Corsi task was not a significant predictor in the previous analysis, it was not included in this analysis. The model, summarized in Table 5, was significant,  $F(3,99) = 20.131$ ,  $p < .001$ ,  $R^2 = 37.9\%$ , as were all predictors.

**Table 5.** Regression analyses with SLT as the outcome variable.

	$\beta$	sr	Sig.	R	$R^2$
MoveSpan	.230	.181	.024	.615	.379
NSPT	.228	.183	.023		
PatSpan	.279	.213	.008		

Note: MoveSpan = Movement Span task; NSPT = Nonsign Paired Task; PatSpan = Pattern Span.

## **CHAPTER 5**

### **DISCUSSION**

The primary aim of this study was to identify predictors of signed word learning. Previous studies in spoken language research have identified spoken-PSTM as reliable predictors of spoken-WL and have also intimated a relationship between spoken-WL and perceptually relevant (i.e., sound-based) STM. Thus, it was hypothesized that movement-based (subsuming signed-PSTM and nonverbal-movement STM) and visuospatial STM would be related to signed-WL. The results of this study confirmed this hypothesis: all predictors were correlated with the signed-WL task with coefficients ranging between 0.40 and 0.54. Moreover, hierarchical regression analyses revealed that the predictors used in this study were chiefly measures of visuospatial and movement-based STM, though there is evidence to suggest that one task, the NSPT, also measures phonetic discrimination. These results will be discussed in turn.

As can be inferred from the range in correlations above, visuospatial and movement-based STM were similarly related to sign learning. While not an explicit hypothesis, this was somewhat surprising as I expected that the strongest predictors would be movement-based; after all, learning signs should be more similar to retaining movements in STM than visual patterns or sequences.

I suspect that the relative equality between visuospatial and movement-based STM may be due, at least in part, to a strategy that utilizes memory for key configurations to aid in the recognition (e.g., SLT and NSPT) and recall (e.g., NSRT and MoveSpan) of human body movements (Vicary et al., 2014; Vicary & Stevens, 2014).

Take for example the sign depicted in Figure 1. A large amount of information can be gleaned by simply referring to the two still frames; all that is left to know is that the type of movement was a straight motion (rather than an arc or some other type of movement). This example implies that in order to correctly recall a movement using this strategy, two configurations must be remembered; it is likely, however, that as the complexity of the sign, and in general human body movements, increases, so too does the load on visuospatial STM.

The regression analyses, in conjunction with the correlational analyses, revealed that the predictors used in this study can be classified as measures of movement or visuospatial STM, i.e., there was no evidence of a need to distinguish signed-PSTM from nonverbal-movement STM or visual from spatial STM. Regarding signed-PSTM and nonverbal-movement STM, this result suggests that in hearing non-signers, the linguistic nature of the predictor is of no consequence. In fact, as previously mentioned, all predictors, including the visuospatial tasks, which bear no resemblance to sign language, were similarly related to signed WL. The implication is that word learning in a new modality relies heavily on perceptual abilities.

In regards to visuospatial STM, prior research has found a division between visual and spatial STM (Darling et al., 2007; Darling et al., 2006; Della Sala et al., 1999), however, this was not found in the present study: the bivariate correlation between the visual and spatial tasks was nearly .7 and when entered into a regression analysis, the spatial task did not significantly account for variance in sign learning over and above the visual task. Della Sala et al. (1999) reports a correlations of .27 and .35 between two versions of a visual STM task, the Visual Patterns Test (VPT; Della Sala, Gray,

Baddeley, & Wilson, 1997) and a Corsi block tapping task. The high correlation between the two visuospatial tasks used in this study may be partly due to the design of the visual task used in this study, the PatSpan. The PatSpan was designed similarly to the VPT, however, in the VPT, the size of the response grid changes as the set size increases and participants are told how many squares a pattern consisted of; in the PatSpan, the response grid remains consistent and participants were never told how many squares a pattern consisted of.

While it is true that all of the predictors used in this study can be classified as movement or visuospatial STM tasks, one task, the NSPT, also appears to measure sign phonetic discrimination ability. Recall that Williams et al. (2016a) found evidence of a significant relationship between English phonetic categorization and sign vocabulary growth. This suggests that phonetic categorization (which requires discrimination between two phones) is important for learning any language, even in a second modality. The contribution that the NSPT made in predicting sign learning (see Table 5) may have been due to this same factor. Of course this is only one possible reason why the NSPT accounted for a significant amount of variance in sign learning over and above movement STM. Another possible explanation for this result is that both the NSPT and sign learning tasks used a recognition format while the MoveSpan task used recall. Still another explanation is that the NSPT had a significant learning component. In either case, these explanations point to the fact that a separate factor, unrelated to nonverbal-movement STM underlies this result.

The results of this study have theoretical and practical implications. First, the significant and fairly strong relationships between the STM tasks and WL displayed in

this study, along with prior studies on the disruption of PSTM, suggest that sign and spoken language acquisition may be dissociable. This means that an individual who exhibits difficulty learning a second language in one modality may have less trouble in the other. The Linguistic Coding Deficit Hypothesis (LCDH) proposed by Sparks and colleagues, for example, holds that L2 learning difficulties stem from the same processes used in acquiring the L1, principally phonological coding processes (Sparks et al., 1998; Sparks et al., 1989; Sparks et al., 2011; Sparks et al., 2006). Learning an L2 in a second modality, however, was never considered. Consequently, our current conceptualization of language aptitude as “equally relevant to any foreign language that the individual might choose to study (Carroll, 1973, p. 2)” will have to be updated to account for second modality, second language learning. This discussion leads to the practical implication that perceptually relevant measures of STM (movement-based and visuospatial in the case of signed languages) may be helpful in L2 course selection and placement.



## **CHAPTER 6**

### **CONCLUSION**

The present study was conducted to investigate predictors of signed word learning. The results indicate that both movement and visuospatial STM are significant and independent predictors. Importantly, the linguistic nature of the STM stimuli (i.e., sign or nonverbal) were irrelevant, suggesting that word learning in a new modality relies heavily on perceptual abilities.

This study was not without limitations. The present study employed only a small number of variables that I (correctly) hypothesized were positively related to each other. This is problematic for at least two reasons. First, there was no evidence of discriminant validity, such as that signed word learning is not as strongly related to auditory STM as it is to visuospatial and movement-based STM. Second, it may be the case that all of our predictors were related to the outcome variable because of some other, mediating variable. A large-scale latent variable study will go a long way to allaying these concerns.

## **Appendix A**

### **Movement Span Scoring Instructions**

#### **Task**

The task was adapted from (Jones, Hughes, & Macken, 2006; Jones et al., 2004).

Participants view sequences of one to five video clips, each containing a movement produced by a model (see Figure 2). Participants are told to mirror the model's movement (if model used left hand, participant uses right hand to mirror the movement).

#### **Scoring**

Scoring is adapted from Wu & Carlson (2014), with additional considerations drawn from Klima & Bellugi's (1979) results of sign confusability studies.

Each movement is scored individually and can be awarded 0, 0.5, or 1 point.

- Full point: All parameters of the movement were reproduced
- Half-point: the movement differed by one parameter from the target OR the movement was reproduced correctly but not mirrored.
- Zero: The movement differed by more than one parameter

#### **Comments**

All movements that are scored less than 1 must have coder comments. Use the following codes along with your own comments.

- 0 = Omission = item was not performed

- I = Intrusion = an item not part of the current set (or even task) was performed (use the other comments section)
- S = Substitution = an incorrect movement, handshape, location, or orientation was used in an item
- A = addition = an extra movement was added to an item
- D = deletion = a movement was deleted from an item

## Parameters

### Handshape

- There are three handshapes in the MoveSpan task: spread hand (ASL 5), flat hand (ASL flat B), and fist (ASL S or A).
- Do not deduct points for small deviations—for example, if the handshape was supposed to be a flat hand but there is a little spread, judge it on whether it looks more like a spread hand or more like a flat hand. Similarly, do not deduct for slight extensions of the pinky or thumb or any other digit.

### Orientation

- Any deviation of about 75 degrees or greater is considered incorrect.

### Location

- Movements done along or referencing a specific part of the body (not including fingers, see below) should be judged correct if they were in the right general physical area.
- Movements pointing to or between specific fingers must be reproduced to those specific locations. IMPORTANTLY if hand orientation is reversed, the

location could be correct even if pointing to an incorrect finger. For example, if the model showed their palm and pointed to the ring finger but the participant showed the back of their hand and pointed to the middle finger, then, assuming all other aspects were correct, this item is given half a point.

- Movements done around the body should be judged using the NSRT (Mann et al, 2010) criteria for location: use general zones such as near the head, near the body, in front of the head, in front of the body, etc.

#### Path Movement

- Path movement is considered incorrect if path movement was added, deleted, performed in the wrong direction, or used a completely different movement.
- Regarding repetitions: do not count! Simply distinguish between “once” and “more than once,” meaning if a movement has repetitions but the participant only does the movement once, then this is incorrect; or if the movement has no repetition but the participant adds one, this is also incorrect.
- Regarding length of path: Use a gross assessment of “short” or “long.” For example, mark as incorrect if the path was supposed to be short but the participant used a large gesture.
- Regarding trajectory: Any deviation of ~30 degrees or more is considered incorrect

### Internal Movement

- The only internal movement in this task is wrist rotation; judge this parameter incorrect if the orientation of the hand is off by about 75 degrees or more.
- This parameter should be considered wrong if any other internal movement is added.

## **Appendix B**

### **Nonsign Repetition Task Scoring Instructions**

#### **Task**

The task was adapted from Wu and Coulson (2014). Participants view video clips of a single nonsign produced by a model (see Figure 3) and are asked to reproduce it. To be consistent with the MoveSpan task, participants were told to mirror the model's sign (if model used left hand, participant uses right hand to mirror the sign). Mirroring is a variation of the original Mann et al. (2010) procedure.

#### **Scoring**

Scoring is adapted from Mann et al. (2010), with additional considerations drawn from Klima & Bellugi's (1979) results of sign confusability studies.

Nonsigns are scored dichotomously (0 or 1) on the following: handshape, path movement, and internal movement. Location errors will be noted but will not be used in calculating scores.

Besides scoring, coders will also provide comments.

#### **Handshape**

- An incorrect handshape may add or delete finger/thumb or use a different handshape (5 instead of B or V instead of K)

- A small deviation in handshape is allowed. For example, if the pinky sticks out a bit while doing a B handshape.
- Deviations in handshape are considered incorrect when a finger/thumb is in a different position or configuration.
- Orientation: any deviation of 75 degrees or greater will be considered an error in handshape.

### **Path Movement**

- Path movement is considered incorrect if path movement was added, deleted, performed in the wrong direction, or used a completely different movement.
- Regarding repetitions: do not count! Simply distinguish between “once” and “more than once,” meaning if a movement has repetitions but the participant only does the movement once, then this is a 0; or if the movement has no repetition but the participant adds one, this is also a 0.
- Regarding length of path: Use a gross assessment of “short” or “long.” For example, mark as incorrect if the path was supposed to be short but the participant used a large gesture.
- Regarding trajectory: Any deviation of ~30 degrees or more is considered incorrect

### **Internal Movement**

- Internal movement is considered incorrect if aperture or trill was added or deleted, wrist rotation, deviation, nodding [extension/flexion] was added or

deleted, if a second handshape's orientation is off by 75 degrees or greater, or if the second handshape is otherwise incorrect.

### **Location**

- Location is considered incorrect
  - If a movement or handshape is incorrectly occluded or exposed
  - For unidirectional movements:
    - If the location of the gesture begins or ends in the wrong general area
      - Around the head/around the body, in front/to the side of the person, etc.
      - Again, judge distance grossly
  - For alternating movements or movements with repetition:
    - The movement should be contained within the same general space, but do NOT count off if the individual begins and ends the movement in the opposite place (e.g., if the movement alternated between right and left but the participant began the movement as left-right, that is fine).

### **Comments**

- Comments must be made anytime
  - A "0" is given for any parameter
  - A difficult decision was made
  - The wrong hand was used



- If the wrong hand is used and this affects the movement or location, make sure to score and comment accordingly
- If the wrong hand was used but movement or location was unaffected, then simply note it here.
- Use the following codes:
  - O = Omission = item was not performed
  - I = Intrusion = an item not part of the current set (or even task) was performed (use the other comments section)
  - S = Substitution = an incorrect movement, handshape, location, or orientation was used
  - A = addition = an extra movement was added
  - D = deletion = a movement was deleted

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